High performance expansion joints for the Incheon Bridge

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Summary

The Incheon Bridge in South Korea is one of the finest examples of bridge building undertaken anywhere in the world in the early years of this century. Exceptional bridges require exceptional components such as the expansion joints which provide a continuous driving surface for traffic at each end of each section of bridge deck, while facilitating all movements of the deck due to thermal expansion and contraction, traffic loading, and all other external effects. This paper describes the project to design, manufacture, transport and install the largest of these expansion joints.

Figure 1: Artist's impression of the Incheon Bridge

1. Introduction

Expansion joints must bridge the continuously opening and closing gap between a bridge deck and the bridge's abutments, or between two sections of bridge deck, often facilitating movements in all three directions and rotations about all three axes while being subjected to millions of axle loads.

Large bridges require expansion joints which can facilitate correspondingly large movements of the bridge deck relative to its abutments, and as the field of bridge engineering develops, with ever-increasing spans, the demands on expansion joints for such bridges continue to increase. *Figure 2* illustrates how bridge spans have increased in recent decades, resulting in greater demand for expansion joints which can facilitate extreme movements.

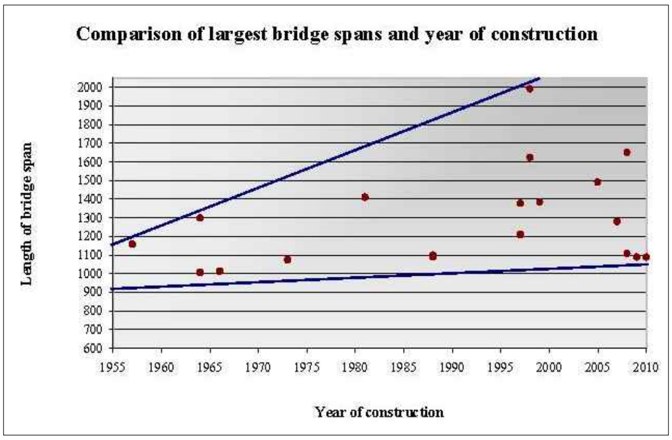

Figure 2: Representation of increasing spans of bridges in recent decades.

Modular expansion joints are often best suited to satisfy these demands, but face a number of particular challenges due to scale in the case of very large bridges.

This paper investigates these challenges, and describes the project to supply the expansion joints for one of the most impressive bridge structures to be built so far this century, the Incheon Bridge in South Korea.

2. The Incheon Bridge

The 12.3km long Incheon Bridge, including a main cable stayed span of 800m, is one of the five longest bridges of its type in the world. Its 33.4m wide steel/concrete composite deck will carry six lanes of traffic 74m above the main shipping route in and out of Incheon port and link the new Incheon International Airport on Youngjong Island to the international business district of New Songdo City and the metropolitan districts of South Korea's capital, Seoul.

The cable stayed section of the crossing is 1,480m long, made up of five spans measuring 80m, 260m, 800m, 260m and 80m respectively, and the height of the "inverted Y" main towers is 230.5m A 1.8km approach span and 8.7km viaduct, both constructed with precast prestressed concrete box girder decks, complete the crossing. Foundations are drilled piles, each 3m in diameter. The total cost is more than $1.4bn, which is funded through a Private Partnership in Investment (PPI), the first in South Korea to involve an outside strategic investor.

3. Principle considerations in the design of very large expansion joints

3.1 Required working life

According to the latest international standards for road bridge expansion joints, the minimum intended working life of expansion joints such as those of the Incheon Bridge shall be at least 40 years for structural parts.

3.2 Applicable traffic loading

Large bridges such as the Incheon Bridge tend to be located on critical transportation arteries

and thus to be used by large numbers of vehicles every day. Assuming a bridge is used by 7,000 heavy vehicles a day, the total traffic volume during a working life of 40 years will exceed 100 million such vehicles or 200 million axle loads. This enormous figure indicates why fatigue is a major issue when designing durable expansion joints and why many expansion joints around the world start failing after only a few years.

3.3 Movement characteristics

Large bridges require expansion joints which facilitate very large movements. The joints of the Incheon Bridge, for example, must facilitate movements of 1,920mm – a very large movement for any type of expansion joint. Such large joints often exhibit quite complex movement characteristics, and the total movement facilitated by the joint during its lifetime - from micro movements due to solar radiation (which arise every time the sun is blocked by a cloud) as well as normal daily and seasonal movements due to temperature change, and other effects - can easily exceed several hundred kilometres.

3.4 Life cycle costs

The initial cost for expansion joints of large scale bridges is usually a very low percentage of the total costs for building the bridge. However, examples of bridges from all parts of the world show that maintenance and repair costs during the full lifetime of an expansion joint can easily amount to several times the initial cost (*Figure 3*), even without considering further resulting costs such as traffic disruption. Therefore it is important that bridge owners and designers consider total life cycle costs in selecting expansion joints. A more expensive joint of higher quality can offer a longer life and require less maintenance, resulting in lower overall costs. A higher quality expansion joint can also better protect the main structure, for example by absorbing impact loads, or by eliminating water ingress into the structure, which can result in corrosion of the joint and structure.

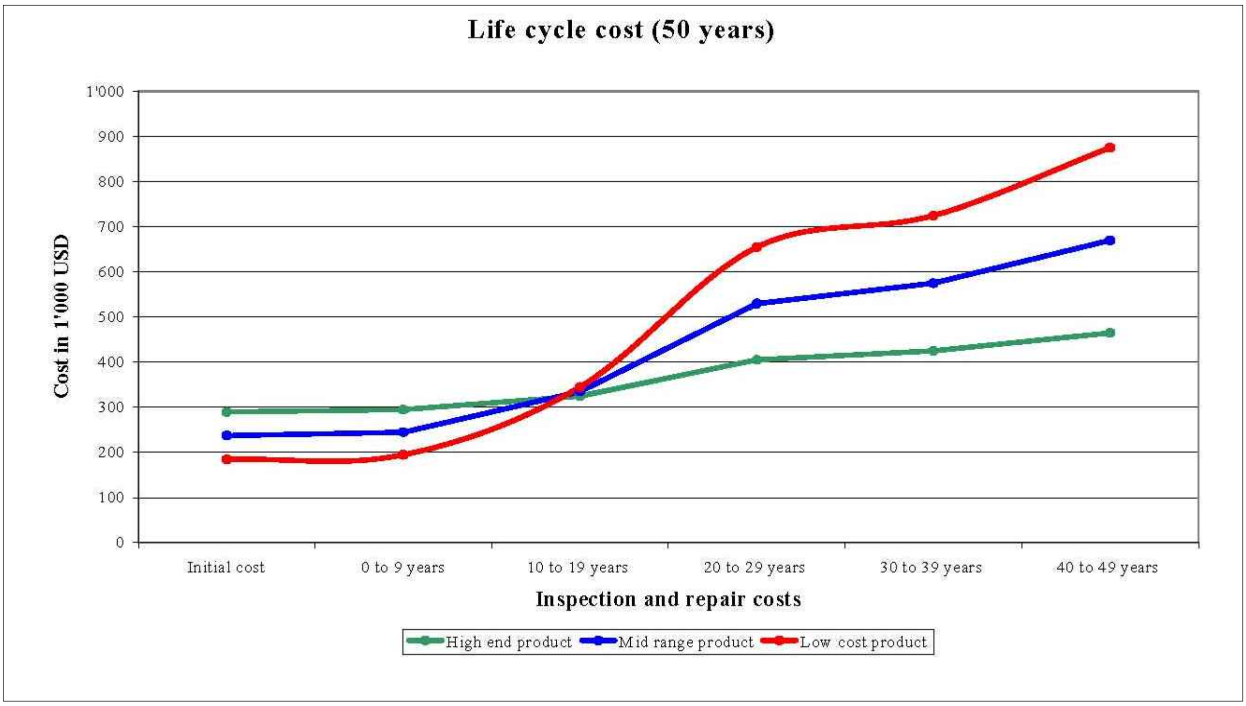

Figure 3: Typical lifecycle costs of modular expansion joints with movement capacity above 1000mm

4. Special features of the expansion joints of the Incheon Bridge

After a comprehensive evaluation process to determine the most appropriate expansion joint solution for this fine structure, the client decided on modular expansion joints, to be delivered by mageba of Switzerland. The design of this expansion joint is based on extensive laboratory and field testing and on complex linear and non-linear dynamic finite element analysis, and the joint has proven its worth on many of the world's largest bridges over a period of several decades.

Following consideration of working life, loading, movement characteristics and life cycle costs, and other project specific factors, it was decided to provide the expansion joints with a number of special features, as outlined below.

4.1 Special sliding material

The sliding material normally used to facilitate the sliding of the moving parts of a modular expansion joint would not withstand the extreme movements of very large expansion joints, and a suitable alternative must be specified. A material which meets modern demands is for instance ROBO®SLIDE, as used to create the sliding surfaces of the sliding bearing and sliding spring shown in *Figure 4*. These components facilitate sliding movement of the lamella beam of the joint over the cross beams which supports it at regular spacings of approximately 1.5m to 1.8m. ROBO®SLIDE is a high grade sliding material with excellent abrasion resistance and very low friction characteristics. Tests carried out on this material showed that over a sliding distance of 2.5km, the friction level is approximately 5 times lower than that of PTFE. The material has also been shown to be twenty times more durable and 2.5 times stronger in compression than commonly used PTFE. The sliding components of the Incheon Bridge were provided with this special sliding material to ensure optimal performance.

Figure 4: ROBO®SLIDE - High grade sliding material in a sliding bearing and sliding spring

4.2 Asymmetrical control system

The symmetrical control systems generally used in modular expansion joints to regulate the widths of the gaps between the joint's lamella beams do not suffice when the movement capacity becomes very large, due to the friction and other forces which arise as the joint opens and closes. To overcome this problem, and ensure that the movement of the joint will be evenly distributed among the joint's individual gaps, an alternative, asymmetrical control system was developed, and implemented on the large joints of the Incheon Bridge. This incorporates a staggered layout of the control springs, with the number of springs being increased at one end of the joint to counteract the build-up of friction forces. *Figure 5* shows the underside of a joint with such a system.


Figure 5: Asymmetrical control system required for large-scale expansion joints

4.3 Durable control springs

The control springs which regulate the gap width between a joint's lamella beams are subjected to additional loading when installed in an expansion joint that must facilitate extreme movements, and must be adapted to suit. For instance, the rubber mixture of mageba's control springs has been optimised to improve overall performance and durability by a factor of 2.5, as verified by testing at an independent institute (see *Figure 6*). These control springs were used for the expansion joints of the Incheon Bridge to ensure satisfactory performance even under the demanding conditions presented by this special structure.

Figure 6: Testing of mageba's 4th generation control spring at -20°C

4.4 Anti-skid protection

As the span of a modular expansion joint increases, so too does the distance a vehicle will have to travel in crossing the joint with reduced ability to brake, especially in wet weather conditions. Large expansion joints therefore require some form of surface treatment to improve tyre grip. A proven anti-skid surface, for example, is ROBO®GRIP. This is a five-layer laminate coating that is applied cold in liquid resin form. It was originally developed for aircraft carrier ships of the British Royal Navy, where high friction and durability under extreme conditions is required. This special surface treatment results in a friction coefficient μ of up to 0.9 and guarantees at least μ = 0.5 over its full service life, even under the most adverse traffic and weather conditions. It is also resistant to pollution and ultra-violet radiation. A joint featuring this anti-skid surfacing is shown in *Figure 7*, and a close-up view showing its texture is presented in *Figure 8*.

Figure 7: Anti-skid coating to ensure traffic safety even in wet conditions

Figure 8: Close-up view of anti-skid coating, showing texture of applied material

4.5 Automated structural health monitoring

Modular joints of such dimensions are complex steel structures with a large number of moving parts For safety reasons, their functioning must be guaranteed at all times for structures of such importance. The movement characteristics of the joint are very complex and difficult to predict due to the size of the joint and the bridge. For this reason the customer desired to have an automated system which would provide permanent real-time information, allowing the behaviour of the bridge deck and the expansion joint to be monitored.

Automated structural health monitoring can provide continuous records of almost any variable in a bridge's condition, such as the position or length of any part, or the force acting on that part. Modern automated systems can also be configured to analyse the data gathered, present it in tabular or graphic format, and make it available to an authorised user anywhere in the world via the Internet. Automatic notification by e-mail of the reaching of predefined alarm values of any measured variable can also be provided. Such systems can also be used to provide structural engineering and bridge usage data for any structure – information which may be of particular interest to the owner of a very large bridge.

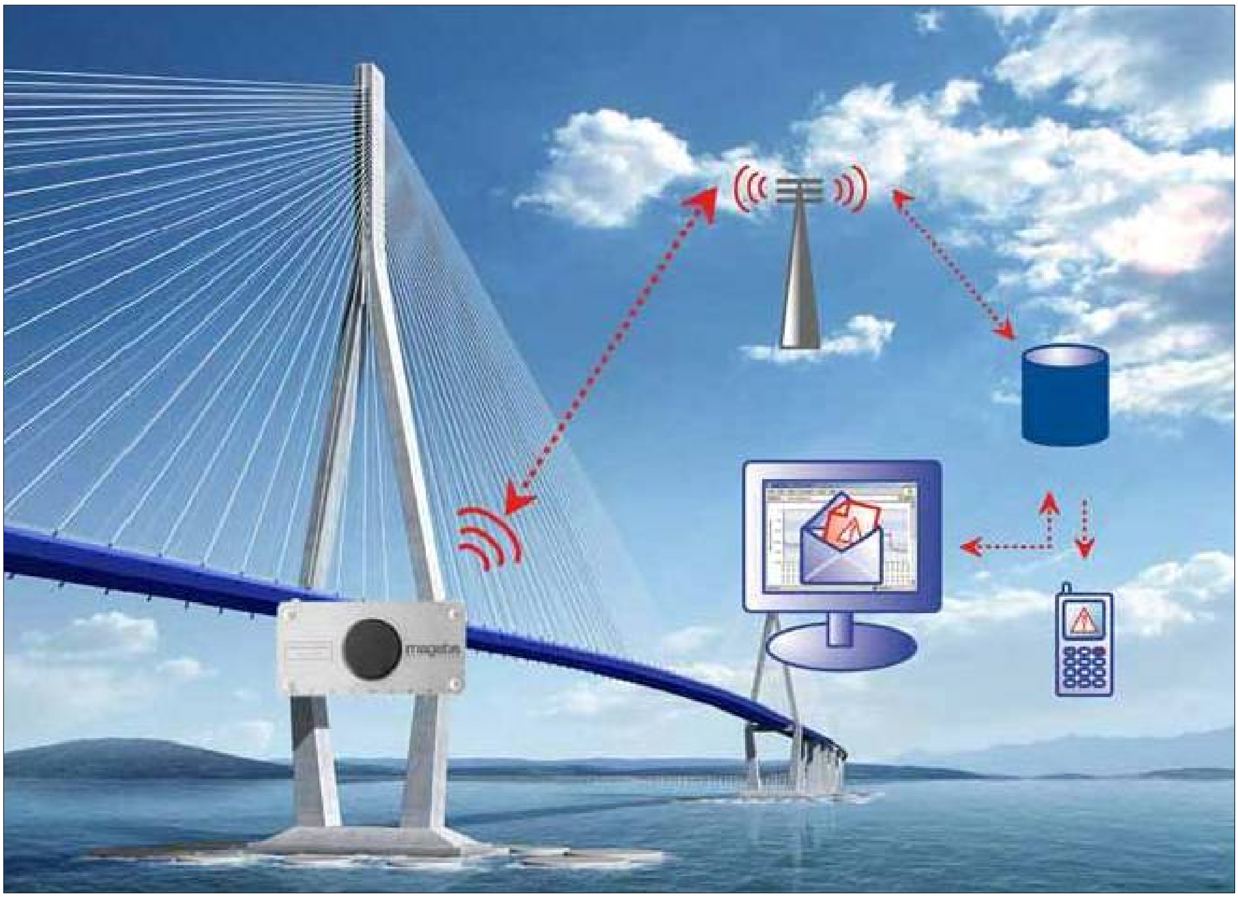

Figure 9: Overview of ROBO®CONTROL system of the Incheon Bridge

Figure 10: Central data logger – the heart of the monitoring system

The ROBO®CONTROL system provided for the Incheon Bridge was developed for long- term measurements without external power supply. A schematic representation of the system is shown in *Figure 9*, and its central computer is shown in *Figure 10*. The system measures the movements and rotations of the structure at regular intervals, and sends the data using UMTS data transmission to a central computer system. The data is then processed and made available to the user. The measured values can either be viewed on the internet via a web interface, or downloaded as CSV files.

Of primary importance is the evaluation of the movements of the expansion joint in the bridge's longitudinal direction. To assess this, the total bridge gap width, and the individual gap widths at the first, second and last lamellas, are monitored. The gap widths are measured using ultrasound sensors. To ensure high-quality measurements, the sensors were installed with protection from wind and rain. With four temperature sensors located at different locations, allowance can be made for temperature effects on the structure.

The system is powered by a solar panel with a buffer battery, and data transmission to the Internet uses mobile phone technology. Thanks to low-energy technologies and a "power on measurement" design, the energy requirements could be minimised, enabling data to be measured and transmitted using the locally available UMTS technology.

Figure 11 shows a view of the *ROBO®CONTROL Dashboard* - the user interface which provides authorised users with easy access to system data from anywhere in the world, requiring only an internet connection and password. Information on the bridge and up-to-the-minute data from the system's sensors is available at the click of a button. The data can be downloaded in tabular form for further analysis, or in graphic form such as shown in *Figure 12*.

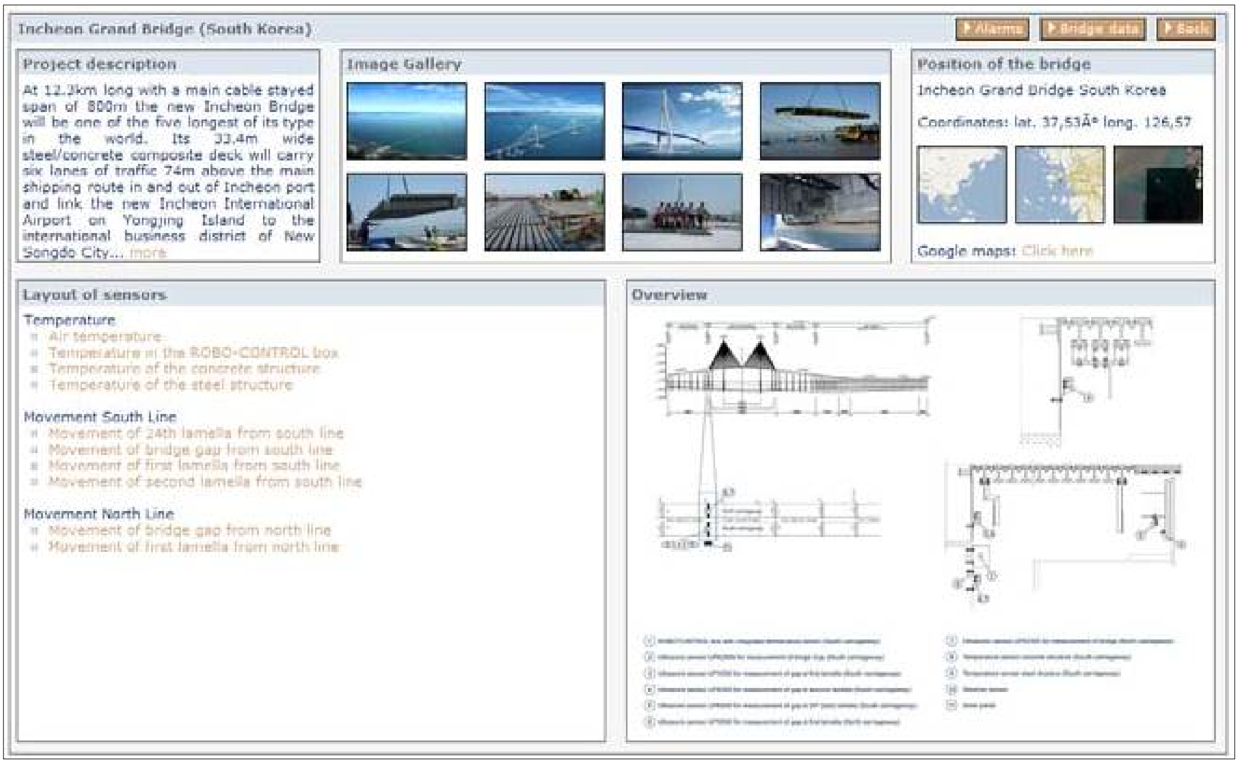

Figure 11: View of the user interface on the internet

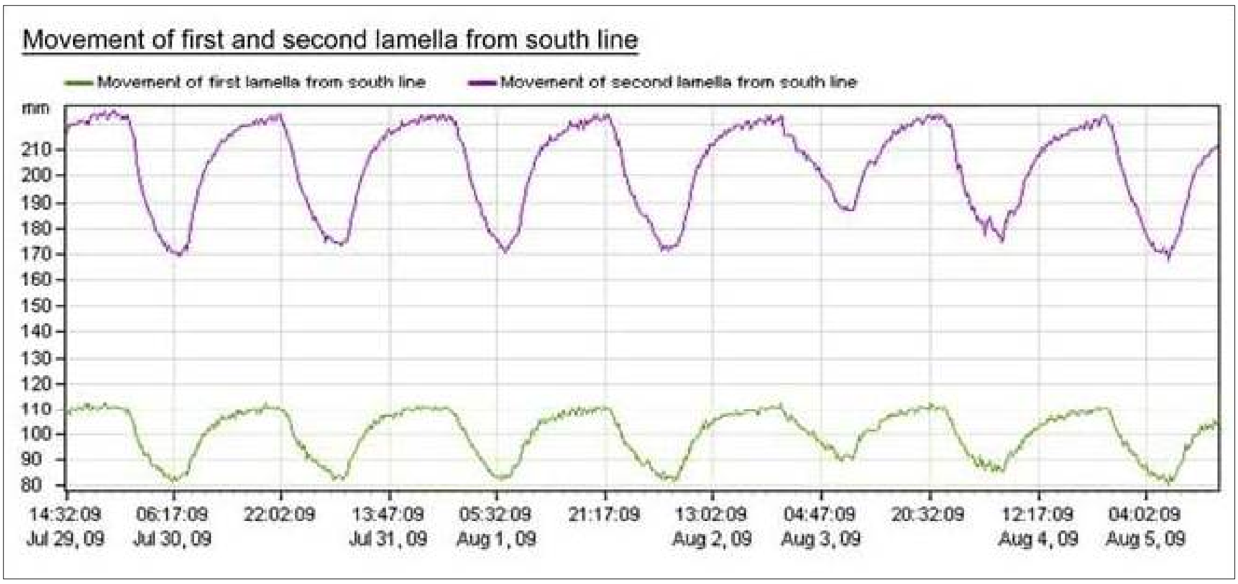

Figure 12: User-friendly presentation of measured data on internet

5. Production and delivery

Once completed, each expansion joint of type LR24 weighed over 42 tonnes, with dimensions (length x width x height) of 16m x 4.9m x 0.8m. A cross section through one of these joints is presented in *Figure 13*. The large dimensions and the high weight required special measures for the transport from the factory in Europe to the bridge in South Korea.

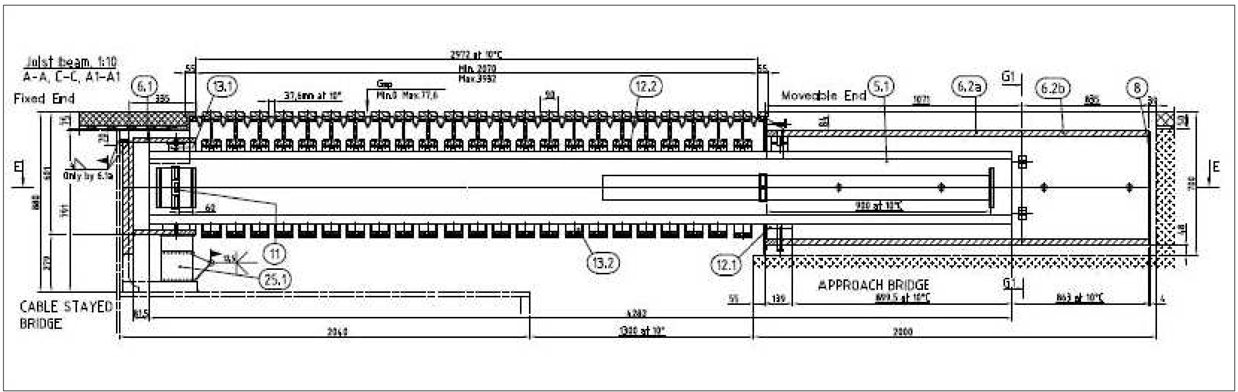

Figure 13: Cross-section of the modular expansion joint type LR24 with 24 gaps and a longitudinal movement capacity of 1,920mm

To enable the joints to be lifted and transported safely, without risk of accidental damage to the joint or injury to those responsible for the transport, transportation frames as shown in *Figures 14 & 15* were detailed and fabricated. The transport by road from the factory in Fussach, Austria to the sea port of Hamburg required special measures and permissions due to the length and width of the loaded vehicles – see *Figure 14*. Loading of two joints into the hull of a ship in Hamburg for the long journey to South Korea is shown in *Figure 15*. Unloading of a joint on site immediately prior to installation is shown in *Figure 16*.

Figure 14: Transportation of one LR24 expansion joint by road from the factory in Austria to the port of Hamburg

Figure 15: Loading of two LR24 expansion joints on a ship for sea transport to South Korea

Figure 16: Unloading of an LR24 expansion joint on site immediately prior to installation

Installation of an LR24 modular expansion joint on the bridge is shown in *Figures 17 & 18*.

Figure 17: Installation of an LR24 modular expansion joint on the Incheon Bridge

Figure 18: Installation of an LR24 modular expansion joint on the Incheon Bridge

6. Installation

The expansion joint supplied for the Incheon Bridge is as follows;

Type	Max Movement(mm)	No of Unit	Amount(m)
LR24	1,920	4	62
LR10	800	4	60
LR5	400	64	1,008

LR24 was manufactured in the Mageba factory in Switzerland and LR10, 5 were assembled in the Sukwoo factory in Korea. Especially we would be better to evaluate the special procedure for the installation of LR24. Considering the difficulty in transportation due to the huge width (over 5m) of LR24, its joist box was connected by bolting to the main body of the joint on the construction site, the Inchon Bridge. One edge profile of LR24 was connected with welding on the steel deck of the bridge and its another edge was connected by concreting after leveling the joint using the special tools for installation and the 250ton capacity of crane. The joints were installed with considering the pre setting value with the temperature, the block out of bridge and the earthquake situation. The joints were installed deciding the level of joint within tolerance +-3mm through the careful and detail measurement because the joint must be set before pavement.

Figure 19:Steel Plate Reinforcement

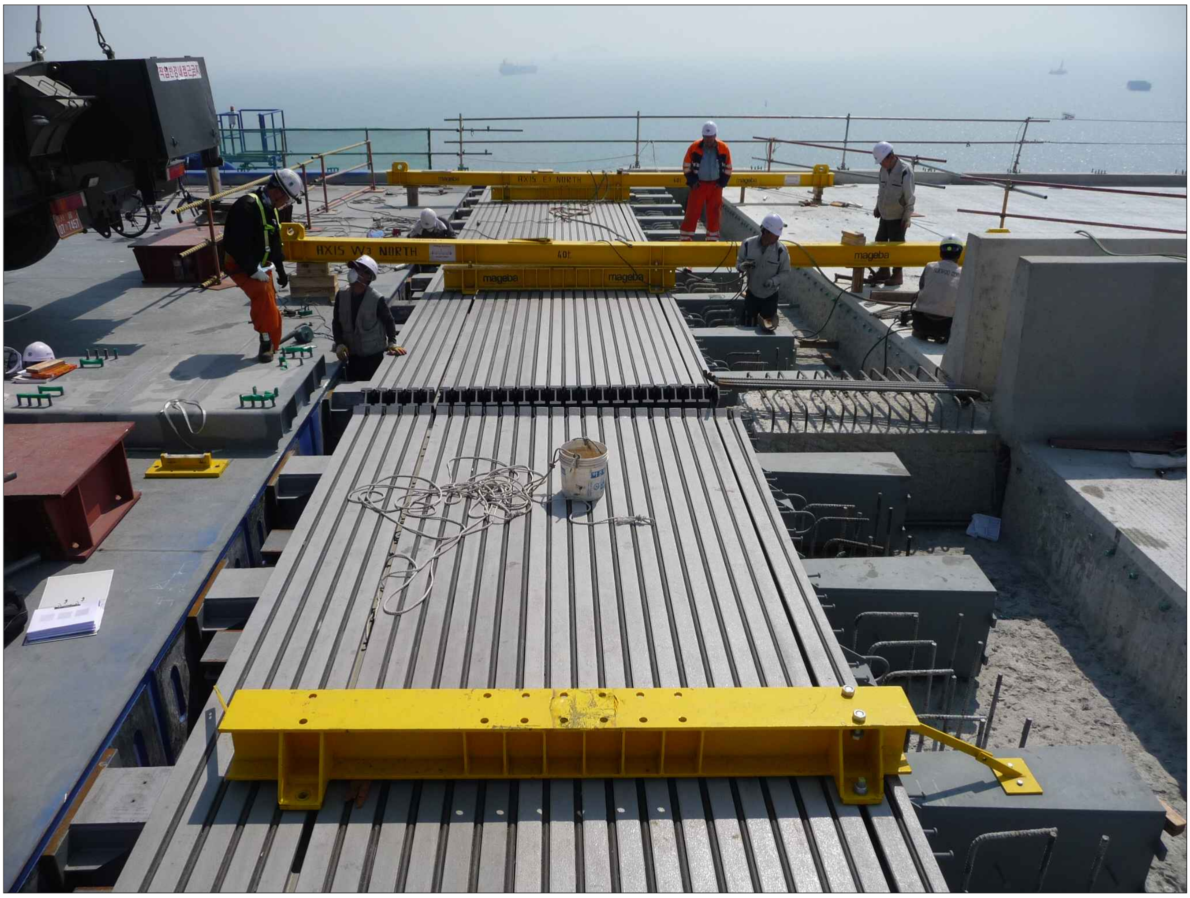

Figure 20: Special spread beam.

Figure 21: Joist box was connected by bolting on the construction site.

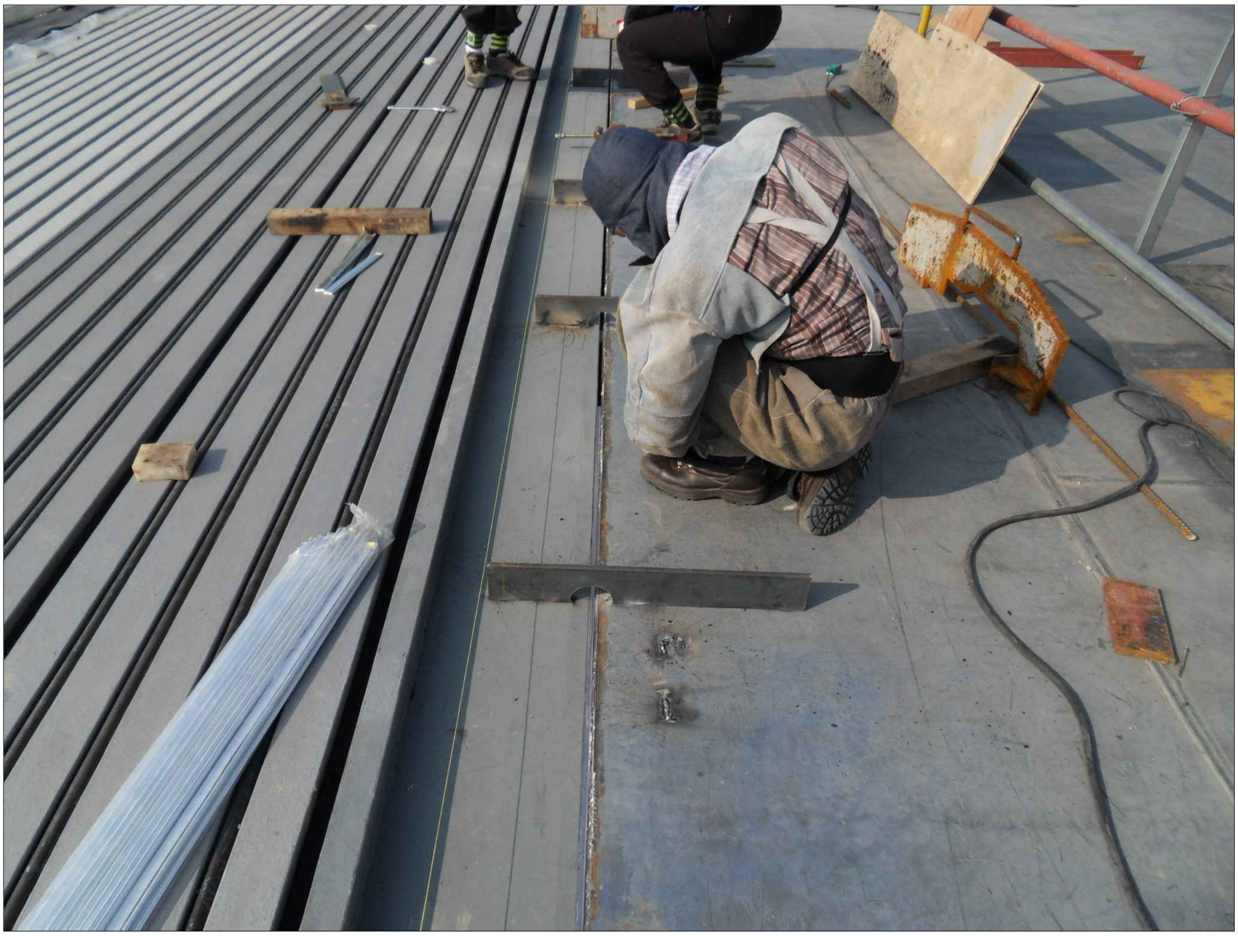

Figure 22: Welding Work by Fully-Qualified Welder

Figure 23 :Rebar Arrangement by Coupler

7. Conclusions

The requirements of very large bridges such as the Incheon Bridge continue to demand ingenuity and innovativeness from the engineers charged with designing and building these extraordinary structures, not least in the specification of the expansion joints which serve such an important function. While the scientific basis for static and dynamic analysis, including fatigue analysis, of the load-carrying structure of large expansion joints has generally reached a high and reliable level, lack of quality in design, production and installation, and insufficient understanding of the complex movement characteristics of large scale bridges can still lead to premature failures of expansion joints. Careful assessment and consideration of movement characteristics is required and manufacturers of expansion joints must continue to strive towards improved designs and quality of individual components, in order to deliver a product which will remain serviceable over the intended lifetime of the joint, with a minimum of maintenance and repair. The careful design and detailing of the modular expansion joints of the Incheon Bridge, with the provision of additional special features as outlined above, ensures that this fine bridge will be well served by expansion joints befitting its status as one of the landmark structures of the 21st century.

Figure 24: Teamwork between bridge owner, constructor and supplier, right throughout the project until installation – a vital element in the successful completion of this demanding project

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